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METHODS FOR EVALUATING WEAK GROUND, LES MINES SELBAIE, QUEBEC

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AUGUST 1985

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MINERALS RESEARCH PROGRAM
MINING RESEARCH LABORATORIES
DIVISION REPORT MRP/MRL 85-112(TR)

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by

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ABSTRACT

The weak ground at Les Mines Selbaie is characterized by zones of kaolinized material occurring in the surface crown pillar. Core recovery from exploration diamond drill holes has been consistently poor, typically less than 50%, through the affected zones. Detailed core logs have been scrutinized and underground access drifts have been mapped to show the absence of a consistent pattern of kaolin material occurrence tied to structure.

Three simple methods of in situ testing have been applied, viz., needle penetrometer, vane shear and borehole pressuremeter. Results indicate that the penetrometer and vane lack sufficient depth of penetration to obtain an unbiased sample. The pressuremeter indicated a range for deformation modulus of between 0.5 and 2.5 GPa. Shear strength values of between 100 and 400 kPa are considered appropriate in the absence of more extensive test work.

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TECHNIQUES D'ÉVALUATION DU SOL TENDRE UTILISÉES AUX MINES SELBAIE (QUÉBEC)

par

G. Swan*

RÉSUMÉ

Le sol tendre des mines Selbaie est caractérisé par des zones de matière kaolinisée qui apparaissent sur les stots de surface. La récupération des échantillons à partir des trous de mine résultant du forage aux diamants est faible, étant habituellement inférieure à 50% dans les zones affectées. Des enregistrements détaillés de forage à carottage ont été examinés attentivement et les galeries d'accès ont été cartographiées en vue de démontrer le schéma d'apparition habituel des matières kaolines en fonction de la structure.

Trois techniques simples ont été utilisées, à savoir, le pénétromètre à aiguille, les cisailles à ailettes et le pressuromètre de forage. Les résultats démontrent que le pénétromètre et les cisailles n'ont pas la profondeur de pénétration qui permettrait l'obtention d'un échantillon intact. Le pressuromètre indique que le module de déformation peut varier de 0,5 à 2,5 GPa. Des valeurs de résistance au cisaillement, se situant entre 100 et 400 kPa sont considérées adéquates en l'absence d'essais plus poussés.

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INTRODUCTION

Les Mines Selbaie has been the site of an on-going research project by CANMET for nearly three years. In this time the characteristics of a complex, weathered rock mass associated with the 'B-zone' orebody have been studied. The mine's surface crown pillar, comprising approximately 40 m of overburden and a subsequent ore pillar, has been the subject of particular scrutiny. Intersecting boreholes have been reviewed for geotechnical data, drifts have been mapped in detail for joints/faults, stress in situ has been measured, rock mass classification has been attempted, etc. (1-4).

On the basis of this work and in concurrence with opinions expressed by mine site personnel (5,6), the most severe ground control problems experienced to date occur in connection with zones of kaolinization. Unfortunately, because of poor core recovery in exploration drill holes, little undisturbed core is available for materials testing of this material. The weakest material recovered to date has provided a compressive strength value of 26 MPa and deformation modulus of 34 GPa (7). These values are not considered at all representative of the kaolinized ore material properties.

Recently, various attempts have been mounted to measure the in situ strength and stiffness variations of kaolinized zones in the surface crown pillar, Les Mines Selbaie. Methods for doing this in soil, and at the other extreme, strong fresh rock, are many and well-established. However, over the intermediate range, relevant to the material of this study, there is a lack of proven techniques which can provide a quick yet adequate appraisal.

The results of using needle penetrometer, vane shear and pressuremeter techniques are described below. Their use in variable strength exposures of kaolin accessed by underground drifts on the mine's 55 m level is discussed.

CORE RECOVERY SURVEY

Prior to initiating a materials test program specifically for the kaolinized material at the mine, extensive surveys of core logs were made to establish the scope of the problem. All drill holes were deemed relevant on the basis of intersecting a block of ore comprising stopes 4 and 5 in which ground control problems had been experienced at and above 120 m below surface. Figure 1.

Core recovery, or CR, is simply the length percentage of core recovered for a given depth of hole drilled. A diamond drill bit functions primarily by shearing the rock, and hence the amount of intact core recovered should reflect to some degree the shear strength of the rock. Core recovery also depends partly on the pressure and volume of water used in drilling, and on the type of drilling machine used. Optimum core recovery is obtained with a hydraulic head machine, since pressure as well as speed of drilling can be controlled. Pressure cannot be controlled with a screw head machine, and hence recovery is not as good. Underground holes at Les Mines Selbaie are drilled using a screw head drilling machine because it is smaller and more mobile than a hydraulic head machine.

The relative effect of these factors on core recovery in poorer quality Selbaie rock was not known a priori. In evaluating the core recovery statistics for holes in the south-lying upper levels of the mine the extent of 'wash-out' is considerable. The drilling crew would be unable to recover any core for several meters because it would be washed out by the water as a gritty mud. To describe quantitatively the amount of wash-out in holes such as these was of particular interest.

The existing core recovery numbers appeared to depend somewhat on which core-logger made the estimation. To eliminate the subjectivity of estimation,

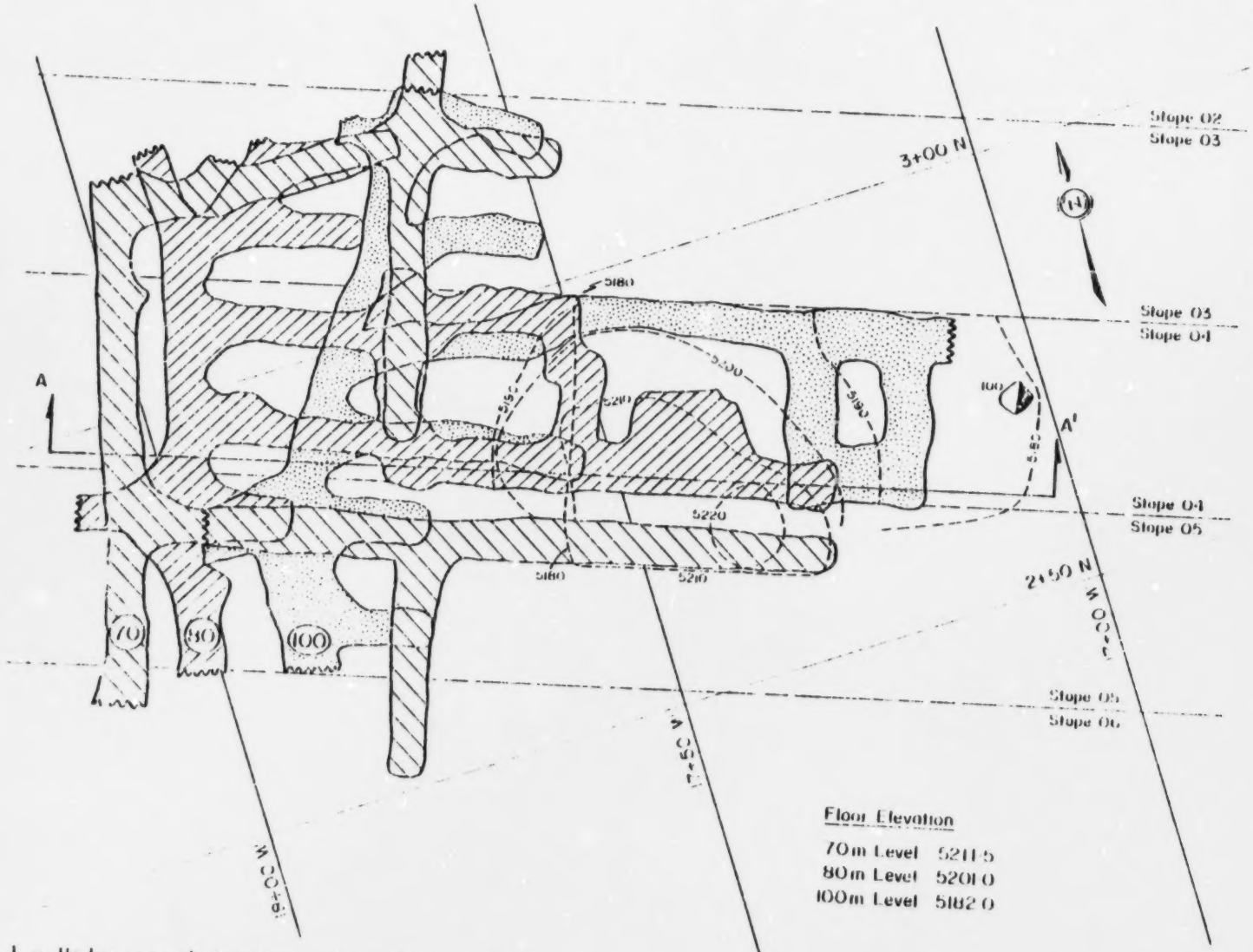


Fig. 1 - Underground development on 70, 80 and 100 m levels showing stope 4 cave-in contours in plan view.

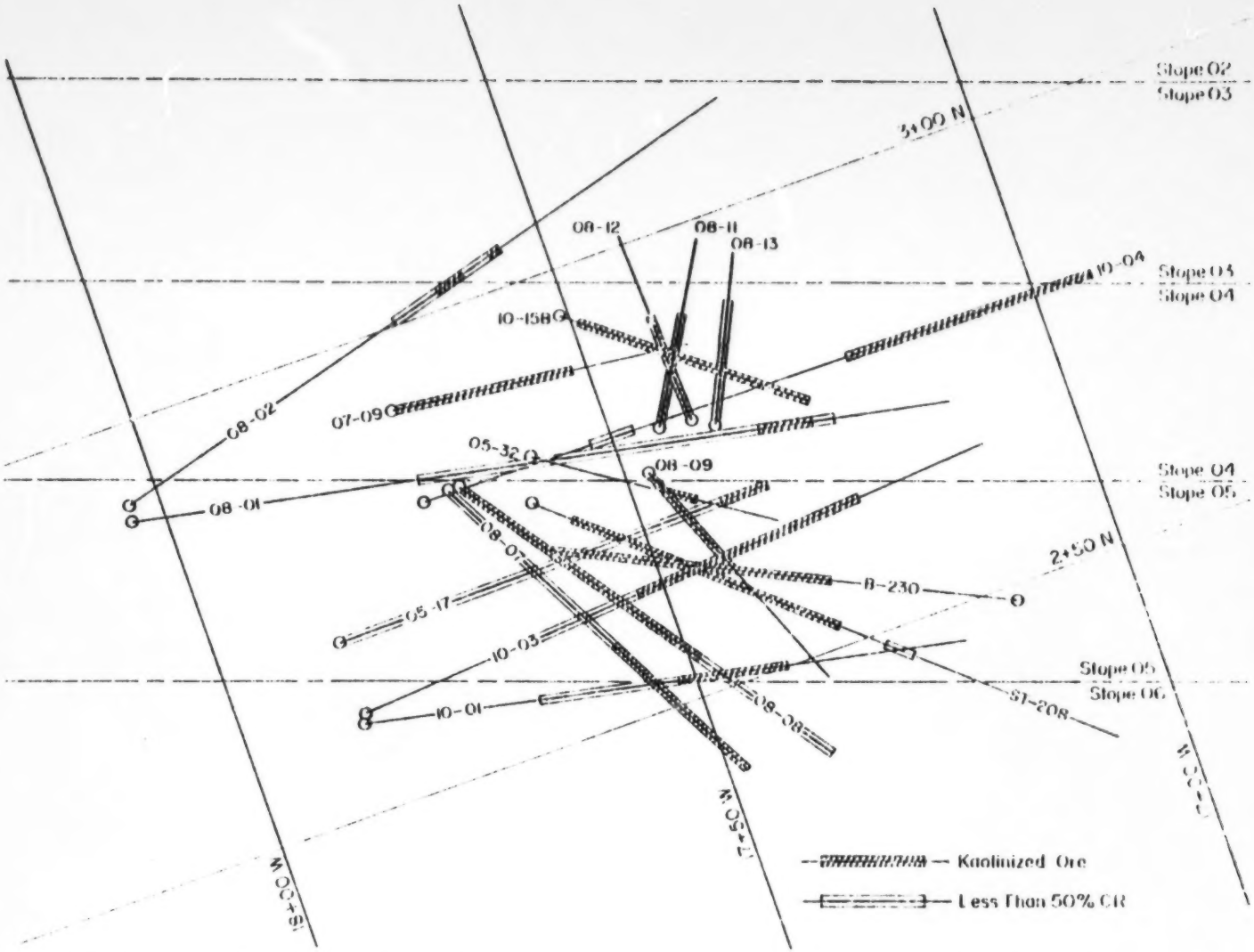


Fig. 2a - Plan view projections of diamond drill holes showing extent of kaolinization and core loss between 100 m level and overburden contact.

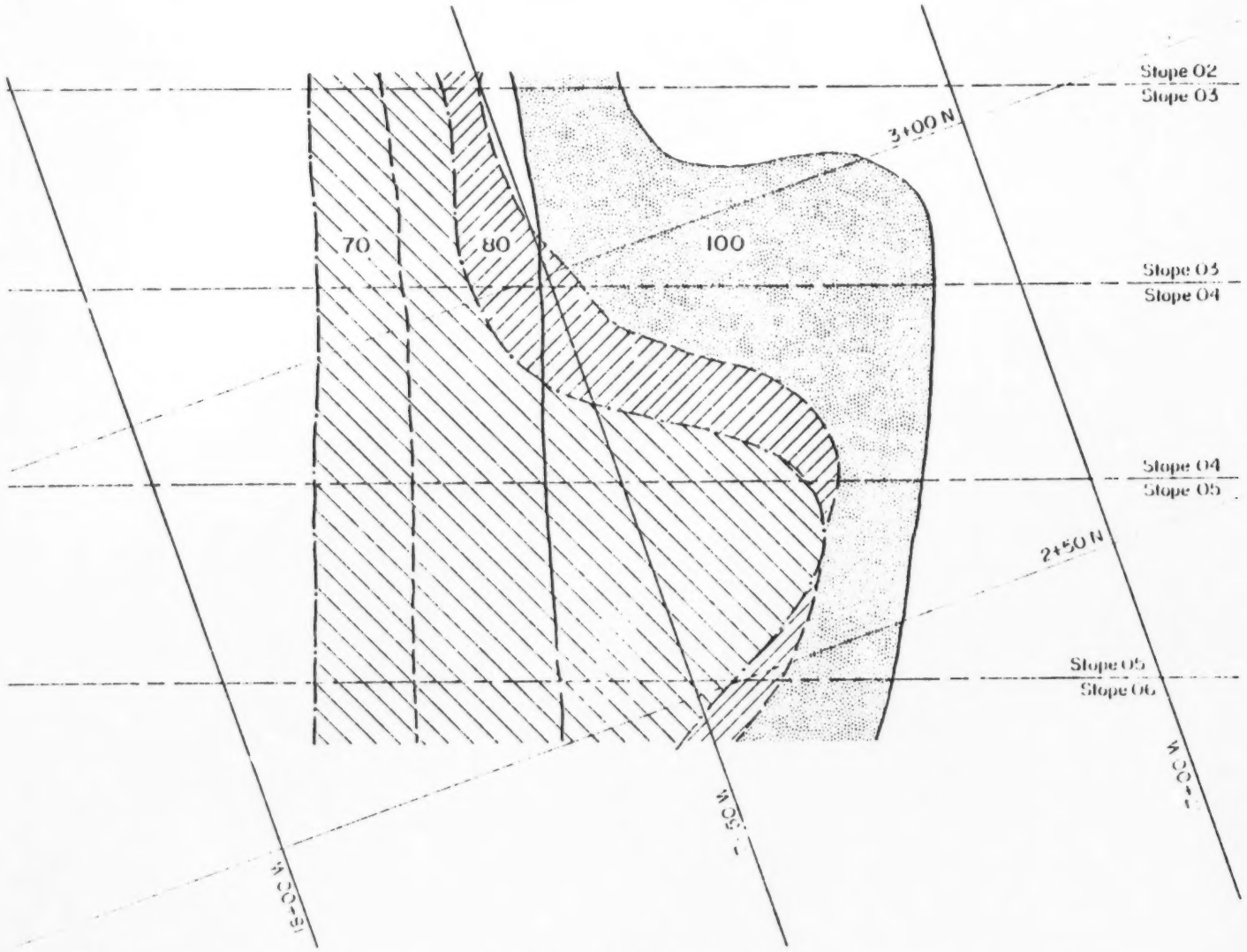


Fig. 2b - Plan view of orebody 'bulge', 70/80/100 m levels, giving a maximum dimension approximately 50 m wide and 22 m long for stopes 4 and 5.

core recovery was carefully measured and recalculated for all the holes. Much of the core had been split for laboratory sampling, and core recovery for the sampled intervals was measured from photographs taken prior to splitting. Unfortunately, photos were unavailable for some of the selected holes.

Much thought was given to choosing an appropriate interval over which to calculate core recovery. The smallest interval possible is about 3 meters, since this is usually the length of the rods used in diamond drilling, and hence, the approximate distance between the depth markers in the core boxes. Large amounts of washout are evident by adjacent depth markers. Core recovery can be calculated over greater intervals if the rock appears to be of similar quality over a considerable depth. This has the affect of averaging small variations. It was decided that for the purposes of this study, an interval between 5 and 7 m was most suitable. This smooths out small irregularities but does not eliminate larger trends. The existing core recovery data was based on intervals varying between 0.5 and 30 m. Since it was preferable to use as constant an interval size as possible, this was an additional reason for recalculating the core recoveries.

For each hole (a record of borehole data is provided in Appendix A), the recalculated core recovery was plotted as a bar graph. These are found in Appendix B. It is interesting to compare these data with stated occurrences of kaolin from core (recovery) logs. These data were plotted for a selection of drill holes, Figure 2.

NEEDLE PENETROMETER

As a method of soil investigation the field penetration test provides a crude measure of relative density and unconfined compressive strength. It can also be applied quickly to obtain a straight line transit survey of underground drifts, etc. For the highly kaolinized zones exposed in the upper

orebody cross-cuts at Les Mines Selbaie this instrument was therefore considered potentially useful. A brief description of the type used and some results from its application on 55 m level cross-cuts at the mine are now given.

While many different types of penetrometer exist, a needle penetrometer was considered most suitable given the extreme variability of the weathered ore material in the dense to very dense soil range. The method involves taking the scaled force reading required to penetrate the material half space a fixed depth. The needle is shaped so that the most dense material provides a reading of 100 at the assigned depth. For consistency of readings the needle should be made of wear-resistant hardened steel. The overall equipment design used conformed to ASTM designation D698.

Initial tests were attempted on a kaolinized zone on the wall of a drift running parallel to the orebody in the north end of the 55 m level of the mine. In most places no penetration was achieved. In the softest places the device was incapable of forcing penetration of the smallest needle, diameter 6.4 mm, deeper than 6 mm. The recommended minimum depth of penetration for this type of test is 76 mm.

The penetrometer was modifed by designing a conical needle with a flat top of diameter 1.6 mm. The tip of the needle was rounded to prevent the edges from catching small hard fragments embedded in the kaolin. Tests with this needle were carried out on the same zone previously attempted with the standard penetrometer needles. Minimum depth of penetration was set at 40 mm. A kaolinized zone was found extending 7 m along the drift 05-2-12. To determine the reproducibility of the test, a set of 12 tests was done at 0.5 m intervals along the wall. The results were highly variable. Index readings ranged across the entire scale of the instrument in some locations, and penetrations were not always possible in others. The rock was found to be

highly heterogeneous in nature with many hard pieces, sometimes several cm in size, embedded in softer kaolin. It was possible to guess at trends along the drift wall by averaging the results for each test series, but the standard deviations were high.

A straight line transit across the zone was made, with penetration attempted every 5 cm. The results were highly erratic, although some trends are identifiable, Figure 3. It was concluded that for material of such heterogeneous nature, the modified penetration test was too small in scale to be useful.

SHEAR VANE TEST

As with the penetrometer, various designs of shear vane exist which provide a measure of shear strength in soils. The method has even been applied to weak rock employing equipment of more robust design (8). Given the difficulties encountered with the needle penetrometer a similar approach was indicated for shear testing of weathered ore. Accordingly, a 50 x 135 mm four-bladed heavy duty vane with a tapered end was designed, Figure 4. Tests were done by driving the vane into the kaolin with a sledge hammer and accomplishing shear using a torque wrench of 475 Nm capacity. To ensure that surface fracture did not occur during shear, the vane was driven as deep as possible before applying torque. The method of preparing each test with a special hole, outlined in (8), was considered but not adopted.

Successful tests were carried out with the heavy duty vane in the kaolinized zone first attempted using the penetrometer. Initially an interval of 0.5 m was used for testing; the average width of the drifts is 4 m, and the mining stopes are approximately 20 m wide. A smaller interval of 0.25 m was also tried but did not yield enough additional information to merit the work involved. An interval of 1.0 m was too large, since some of the kaolin

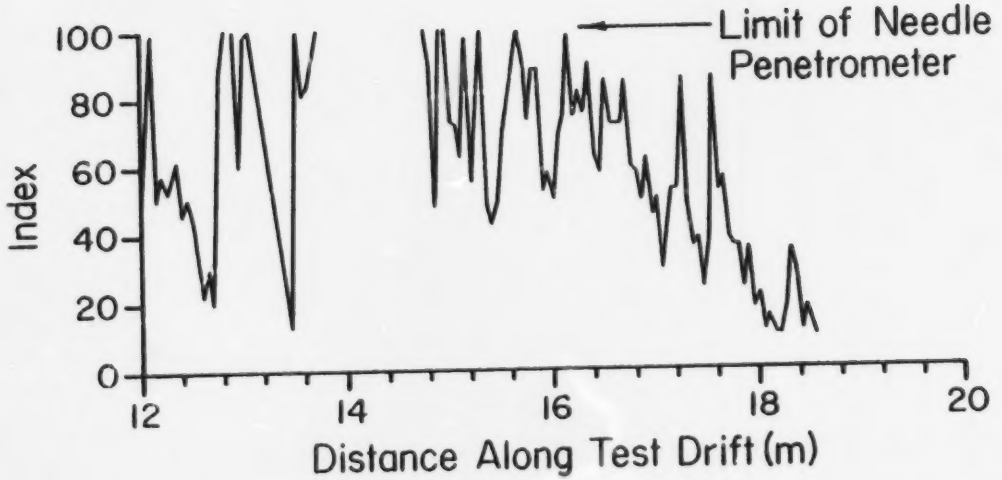


Fig. 3 - Results from needle penetrometer survey of 05-2-12 drift.

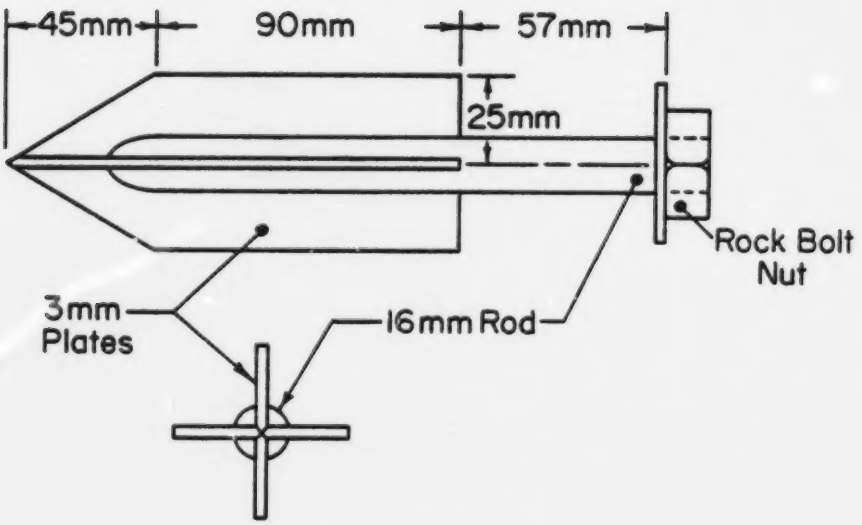


Fig. 4 - Heavy duty shear vane used for testing kaolinized ore zones.

exposures are only 0.5 m in extent. A result for the same drift in which kaolin zones were tested with the penetrometer is plotted in Figure 5. Agreement in terms of shear strength between the two tests is evident from this Figure. The correlations with shear strength were obtained as follows.

Strictly speaking, the reliability of any test of this type must be verified by control or calibration tests. For a vane tester the shear strength τ can be calculated in theory from:

$$\tau = 2T/(\pi d^2 D) \qquad \text{Eq 1}$$

where T is the maximum torque at failure, d is the vane diameter and D the depth of embedment. The heavy duty vane tester, Figure 4, should therefore indicate a shear strength given by:

$$\tau_V = 3.07 \times 10^3 T \text{ [Pa]} \qquad \text{Eq 2}$$

where T is in N-m units. With the help of calibration tests performed on artificial, kaolin-based materials (obtained from L.V. Lomas Chemical Co. Ltd., Ontario) the actual correlation between shear strength, τ, and vane shear strength, τ_V, is plotted in Figure 6. The solid line is the best fit to experimental data points identified as 'vane' in this Figure. In addition to the vane calibration curve, results from simultaneous testing of kaolin-based specimens with the needle penetrometer are plotted from which an independent correlation with shear strength is obtained.

Using these correlation curves the results from a detailed survey of kaolin alteration in the south side of cross-cut 05-1-04 can be assessed. The visual appearance of this wall material can be appreciated in Figure 7. Results from the vane tester confirm the highly variable nature suggested in the photograph. Shear strength as a function of distance along the wall of the drift is plotted in Figure 8. Further evidence of the kaolin's presence can be gauged from the core recovery of drill hole 05-15 which runs sub-parallel to the drift, Figure 9. These data are included in Figure 8 for

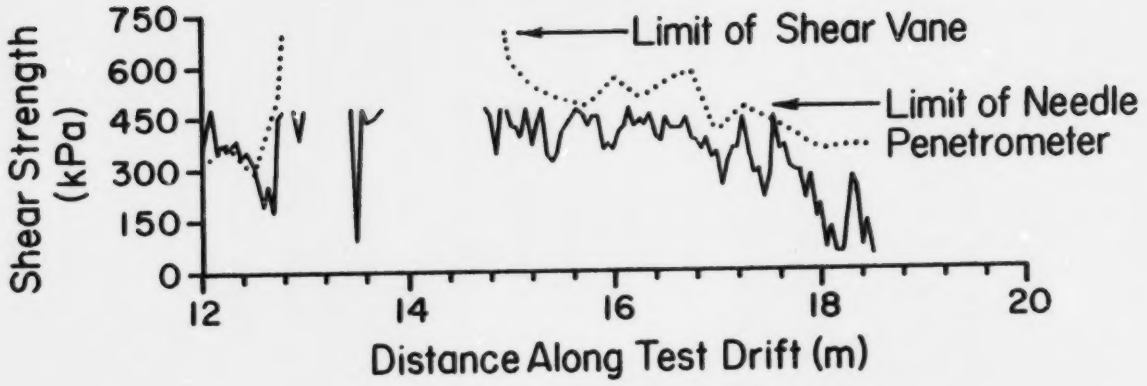


Fig. 5 - Shear strength variation along test drift 05-2-12 according to shear vane and needle penetrometer surveys.

--- needle penetrometer
.... shear vane

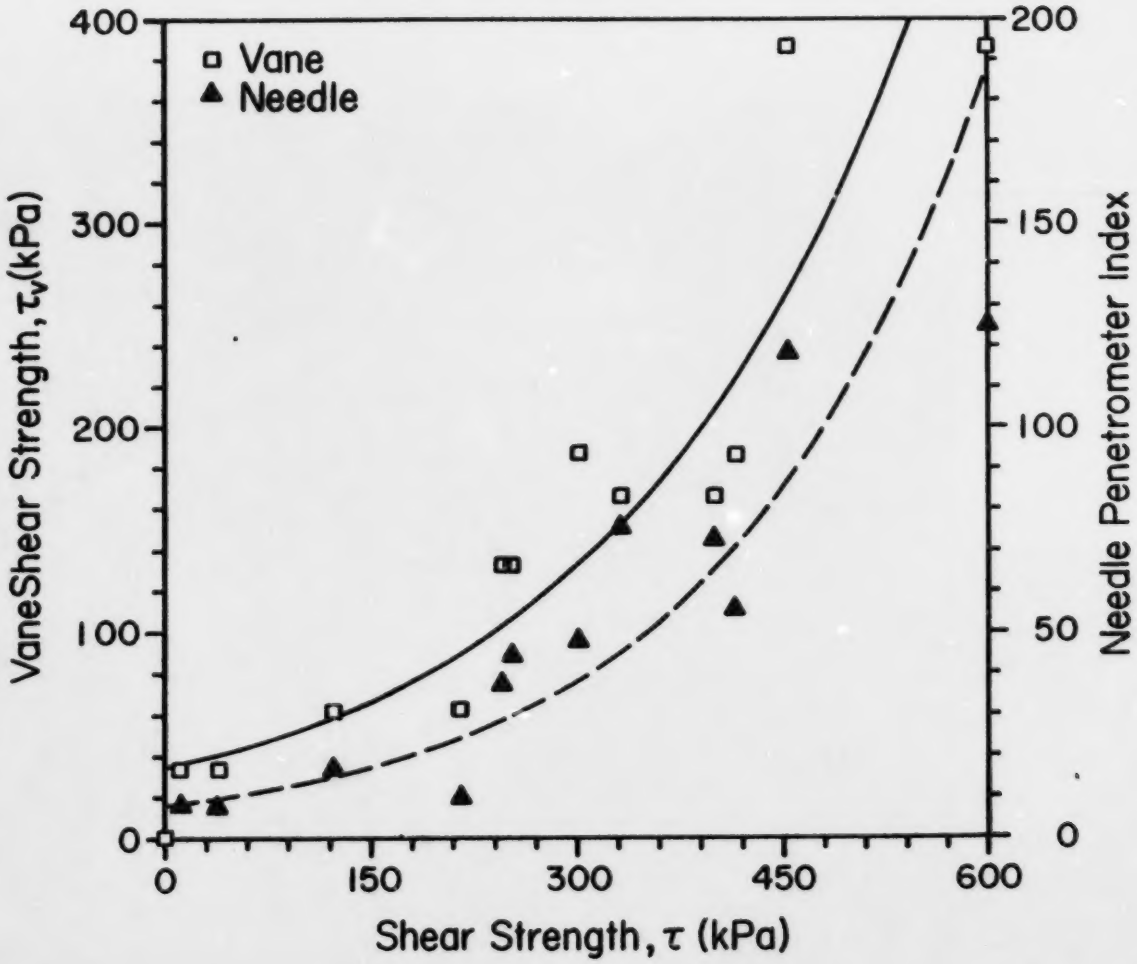


Fig. 6 - Calibration data for shear vane and needle penetrometer.

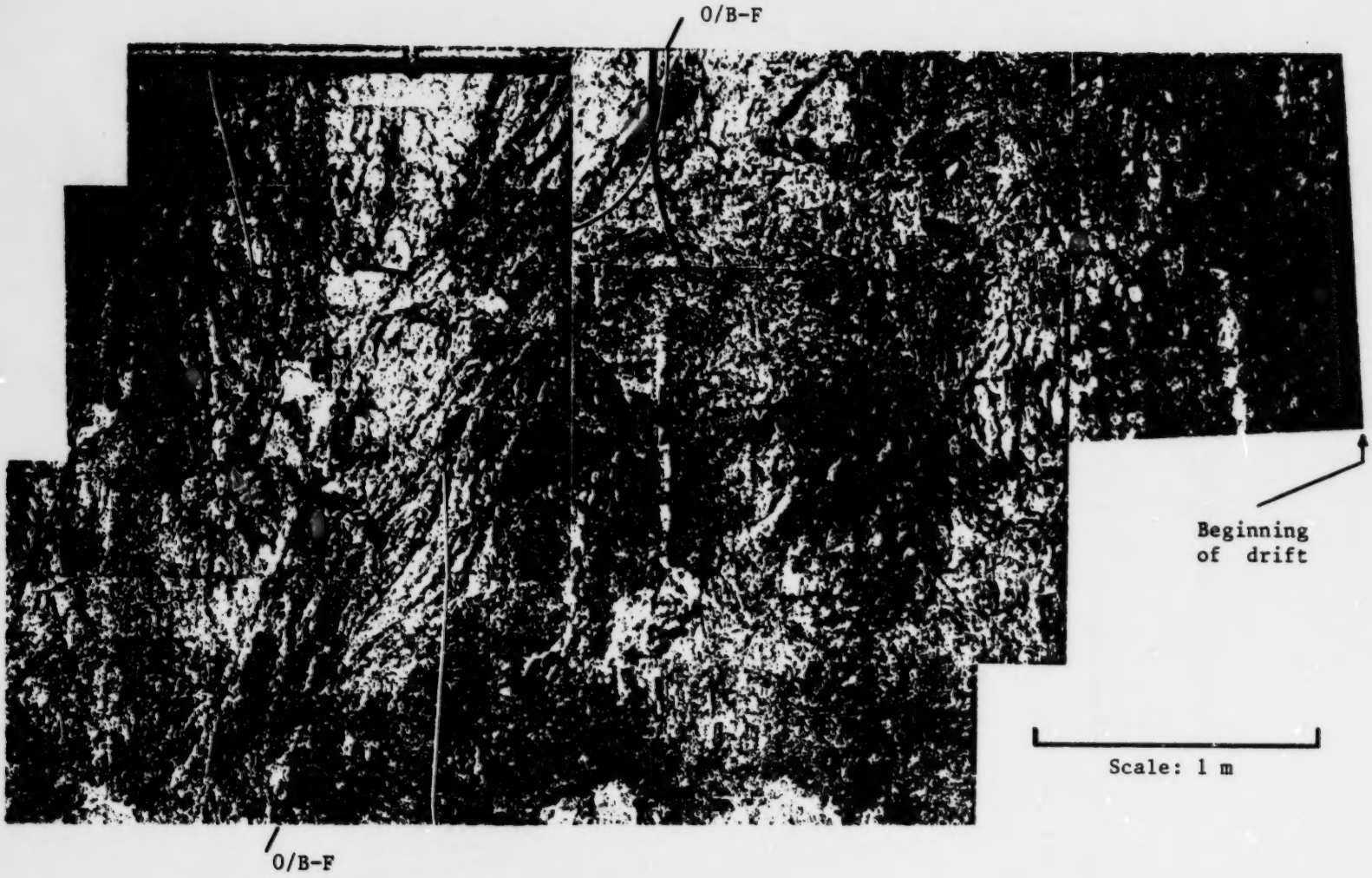
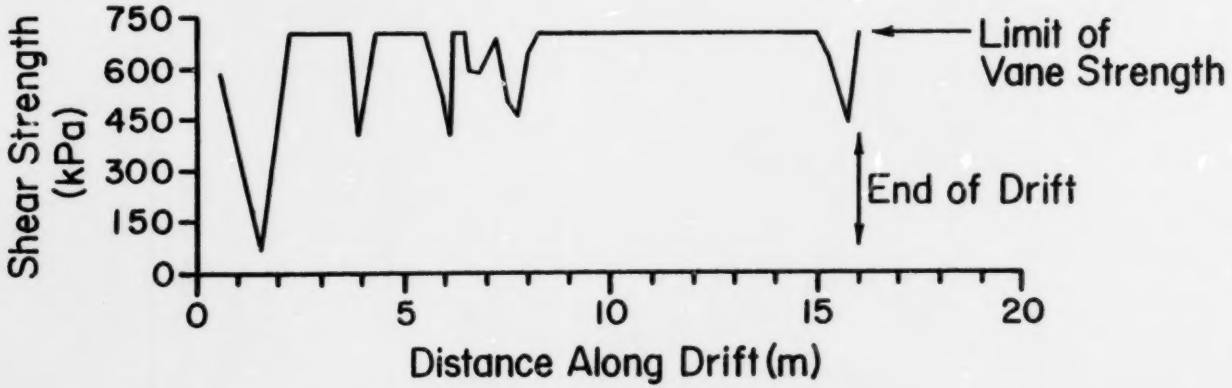


Fig. 7 - South side wall of cross-cut 05-1-04 showing orebody fault and bleached/kaolinized rock mass.



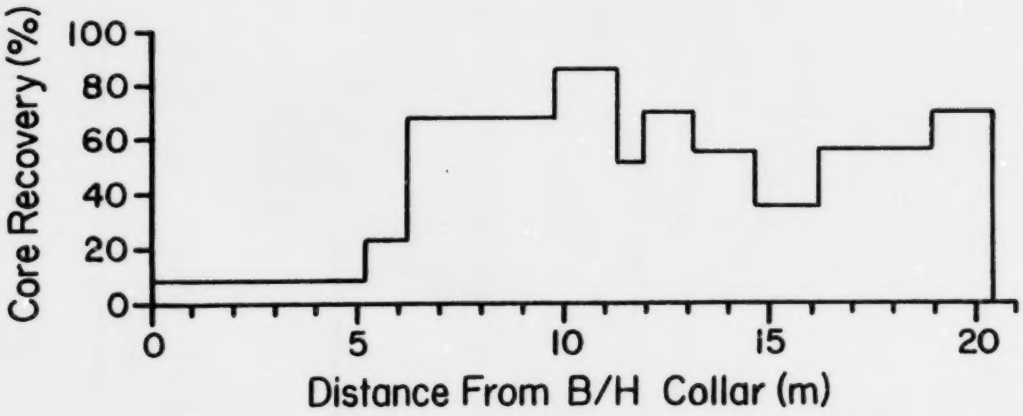


Fig. 8 a) Vane shear strength along south wall of 05-1-04 cross-cut.
b) Core recovery data from diamond drill hole 05-15.

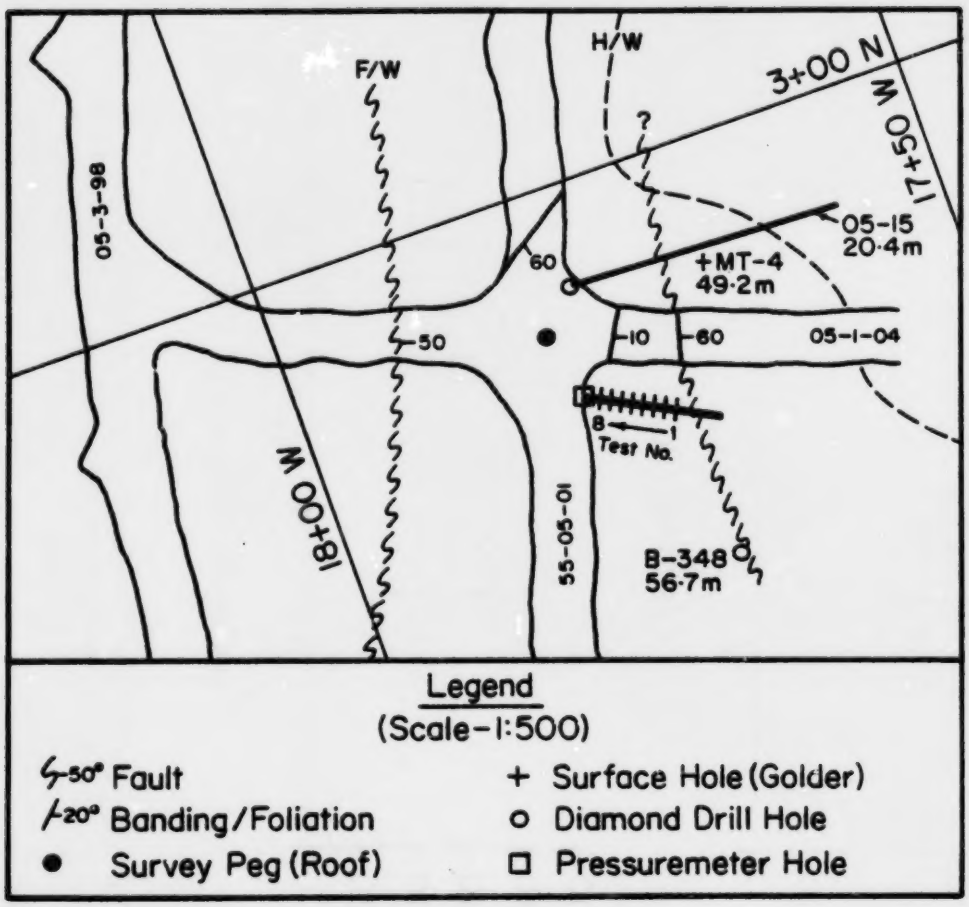


Fig. 9 - Details of kaolinized zone selected for testing program taken from 55 m level mine plan.

comparison.

PRESSUREMETER TEST

Of the testing methods described in this report the pressuremeter is considered by many to provide a more realistic assessment of soil behaviour under load (9). This statement is made on the basis of the pressuremeter's size in relation to the scale of material variation under test. Thus, compared to the needle penetrometer, pressuremeter data relate to macro-scale behaviour beyond the immediate surface effects of a half-space.

The pressuremeter used to test the kaolin material at Les Mines Selbaie measures 1 m x 115 m diameter and has been fully described elsewhere (10,11). The pressuremeter hole was sited to run sub-parallel to cross-cut 05-1-04 (see Figure 9) and was drilled 117 mm diameter a distance of 10 m. A tricone bit was used with a minimum of water flushing. Eight tests were performed in all at approximately 0.75 m intervals along the borehole. Pressure-volume curves up to the operational limit pressure of 2.1 MPa are shown in Figure 10.

Assuming a Poisson's ratio = 0.4, the deformation modulus values calculated from the pressure-volume curves are given in Table 1. These data are plotted in Figure 11 as a function of position along the sub-parallel cross-cut 05-1-04. Vane shear strength from the south wall survey described above are plotted in the same Figure for comparative purposes.

DISCUSSION

It can be easily appreciated from Figure 2 and Appendix B that the orebody kaolinization is pervasive within the upper confines, i.e., above 100 level) of stopes 4 and 5. Where core recovery is less than 50% it must be assumed that the lost core is intensely kaolinized and not simply brecciated. This follows from unsuccessful attempts to correlate the relatively few

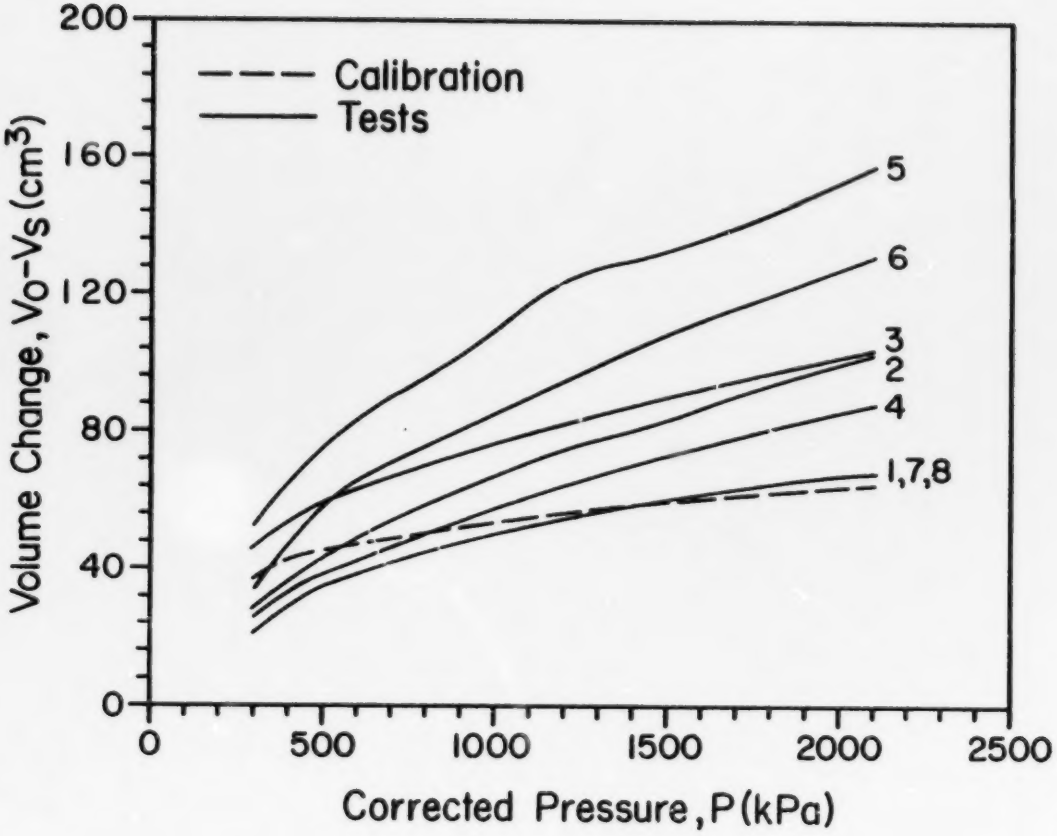


Fig. 10 - Pressure-volume behaviour recorded from pressuremeter tests in kaolinized material, 55-05-01 dritt.

Table 1 - Pressuremeter results summary

Test	Collar Distance (m)	V_o (cm^3)	2r (mm)	Deformation Modulus (GPa)
SELH01	6.42	149.5	122.3	1.25
SELH02	5.66	144.6	122.2	0.38
SELH03	4.92	159.9	122.5	0.67
SELH04	4.16	134.6	122.1	0.49
SELH05	3.42	267.1	124.4	0.28
SFLH06	2.66	154.1	122.4	0.35
SELH07	1.92	147.3	122.3	2.46
SELH08	1.16	143.9	122.2	1.46

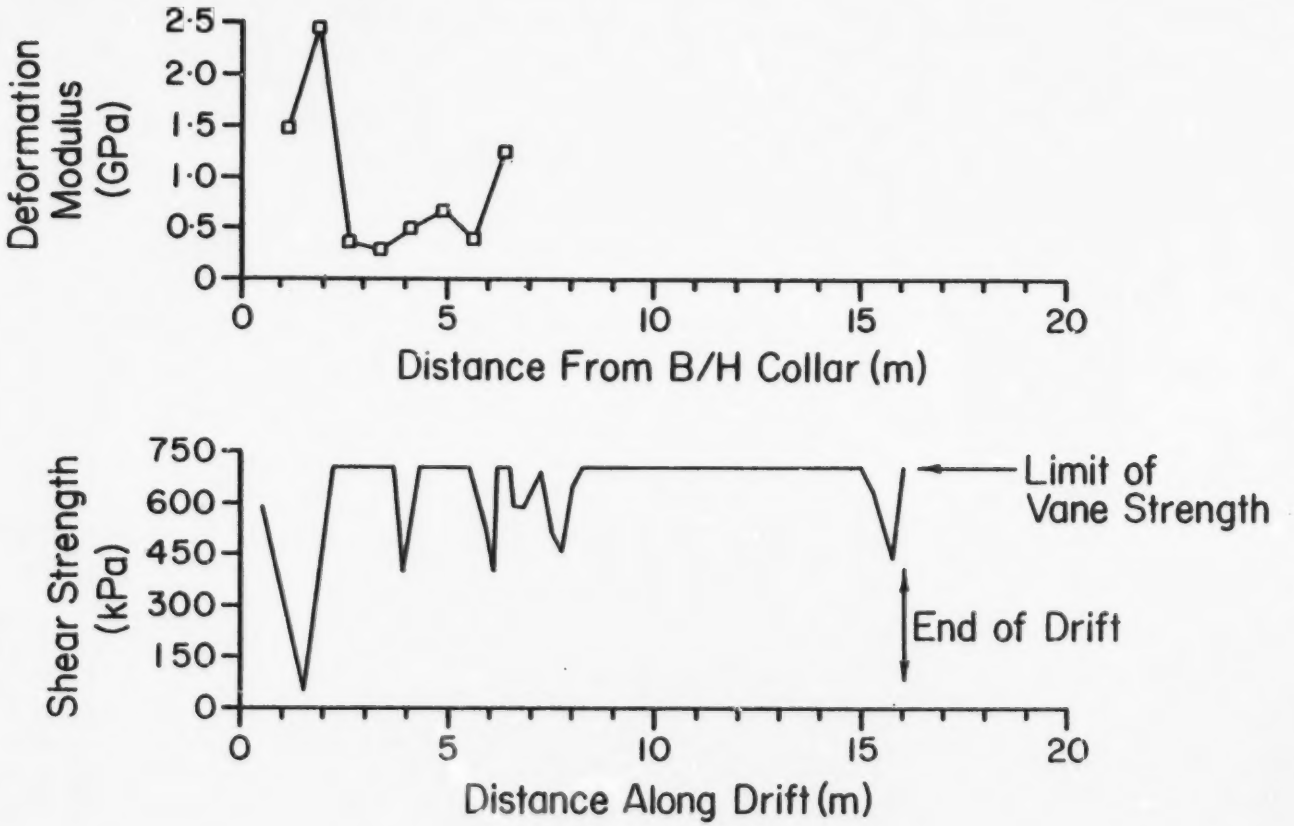


Fig. 11 - a) Deformation modulus at eight sites from pressuremeter tests.
b) Vane shear strength along south wall of 05-1-04 cross-cut.

orebody faults/fractures observed in line mapping with the relatively frequent occurrences of borehole wash-out (4). Furthermore, attempts to identify global trends or persistence to the latter, which might thereby imply some strongly associated structural discontinuity, have for the most part failed. The material therefore resembles something in character to 'cherry cheesecake' - a two phase material with ore 'cherries' in a graded kaolin matrix.

Both the needle penetrometer and vane shear test results tend to confirm this description. Unfortunately, since neither test was performed on a fresh wall exposure, a bias probably exits in favour of the more durable and harder material. This too is confirmed to a degree by the consistently 'soft' pressuremeter results obtained in an essentially undisturbed hole through the same rock mass.

Considering, therefore, the choice of appropriate shear strength and deformation modulus values for this weak rock material, upper and lower bounds remain to be fully established*. Based upon field work reported above and in (7), some values are provisionally suggested in Table 2.

ACKNOWLEDGEMENTS

The author wishes to acknowledge assistance from G. Vaillancourt, Mining Technologist, Elliot Lake Laboratory and also P. Friedrich and M. Jolink, Waterloo Coop Students, in providing field work support. At Les Mines Selbaie, Y. Fourmanoit and D. Cutting were instrumental in providing all necessary backup with respect to engineering and geological services.

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* D.S.S. contract 15SQ.23440-5-9017 entitled "Modelling of Surface Crown Pillar, Les Mines Selbaie", has been issued with this in mind.

Table 2 - Suggested shear strength and deformation modulus values for four grades of weak rock, Les Mines Selbaie.

Grade	Rock Character	Shear Strength (kPa)	Deformation Modulus (GPa)
1	Durable, relatively unweathered, continuous rock.	2500	34
2	Durable, relatively unweathered, but jointed rock.	1000	14
3	Moderately kaolinized, strongly two-phased, continuous rock mass.	400	2.5
4	Highly kaolinized, weakly two-phased, continuous rock mass.	100	0.6

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APPENDIX A

Diamond drill holes reviewed by CANMET
for core recovery and occurrence of kaolin

Note - All Azimuth data are measured from true north; grid north has an azimuth of 22.7°.

- All inclination data are measured positive up.

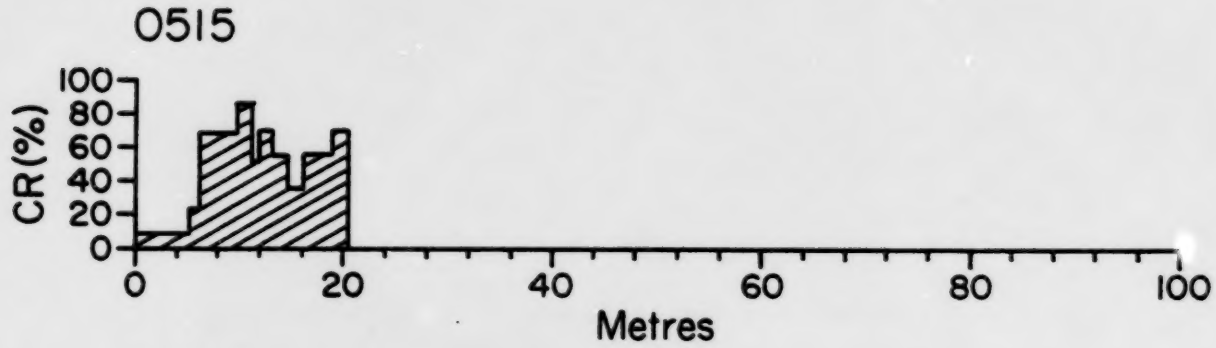
B/H	Hole No.	Azimuth	Incline	Easting	Northing	Elevation	Length
1	B203A	192.8	-58	-1747.39	300.79	5278.27	71.68
2	05-17	89.92	0.54	-1785.58	268.42	5226.27	51.51
3	05-32	125.23	-8.97	-1757.94	280.08	5225.71	31.70
4	08-09	153.63	-0.35	-1748.70	274.64	5202.69	30.48
5	10-15B	134.5	40.53	-1749.15	292.84	5183.74	35.36
6	08-01	101.46	2.01	-1803.81	289.38	5202.36	91.14
7	07-09	94.8	0.67	-1770.91	290.48	5211.63	34.44
8	08-02	75.8	0.97	-1803.90	290.43	5202.34	79.25
9	08-11	28.07	-29.89	-1745.20	279.37	5201.36	26.21
10	B207	269.7	-55	-1673.52	300.33	5277.65	299.36
11	B230	296.5	-58	-1710.23	245.0	5277.37	119.87
12	07-03	93.7	15.06	-1815.63	240.06	5214.52	73.15
13	08-03	127.27	1.35	-1803.96	289.60	5202.35	79.25
14	08-04	66.91	-0.04	-1808.68	293.14	5202.57	64.92
15	08-07	152.95	0.09	-1770.06	281.86	5202.06	45.42
16	08-08	143.3	-14.72	-1769.77	281.98	5201.49	53.95
17	10-03	88.25	15.01	-1785.97	261.50	5184.17	76.81
18	10-04	90.89	1.18	-1771.86	279.50	5183.52	77.72
19	ST-208	130.3	22.3	-1758.33	274.32	5160.92	61.00
20	ST-214	266.18	21.70	-1653.08	241.25	5164.48	150.98
21	B350	267.30	-71.20	-1725.43	289.47	5278.54	106.68
22	ST-200	142.30	20.00	-1746.66	344.13	5160.12	84.61
23	B348	-	-90.0	-1773.00	270.00	5278.18	56.69
24	B351	-	-90.0	-1790.00	250.00	5277.61	11.93
25	07-11	103.70	-0.38	-1780.11	254.72	5212.69	48.46
26	07-15	109.97	79.00	-1781.10	254.60	5216.01	22.86
27	07-17	251.97	60.00	-1782.62	253.66	5215.58	25.60
28	07-18	133.97	50.00	-1781.26	253.61	5215.61	25.60
29	08-10	4.22	-24.79	-1746.22	279.86	5201.22	26.82
30	08-12	1.42	-20.05	-1741.07	278.40	5201.67	22.56
31	08-13	25.59	-29.24	-1740.24	277.23	5201.77	22.86
32	10-01	103.35	6.70	-1785.90	261.03	5183.80	68.58
33	10-14	106.28	40.33	-1749.60	294.35	5185.78	35.05
34	05-15						

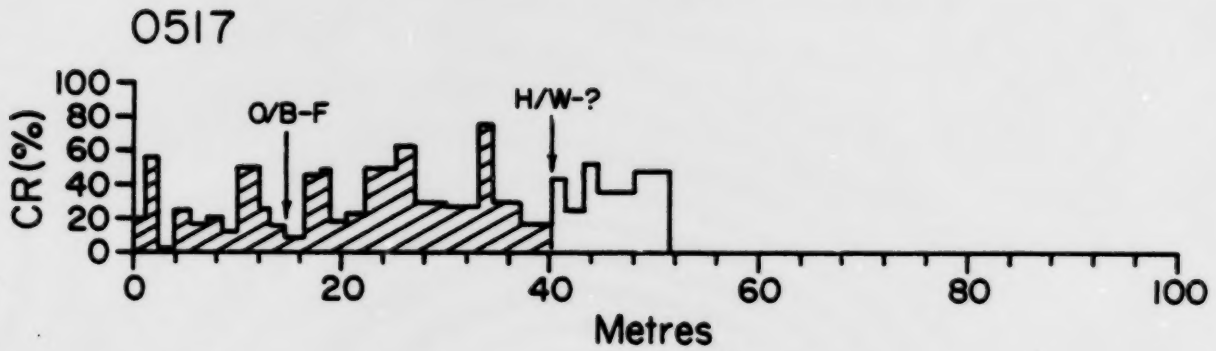
APPENDIX B

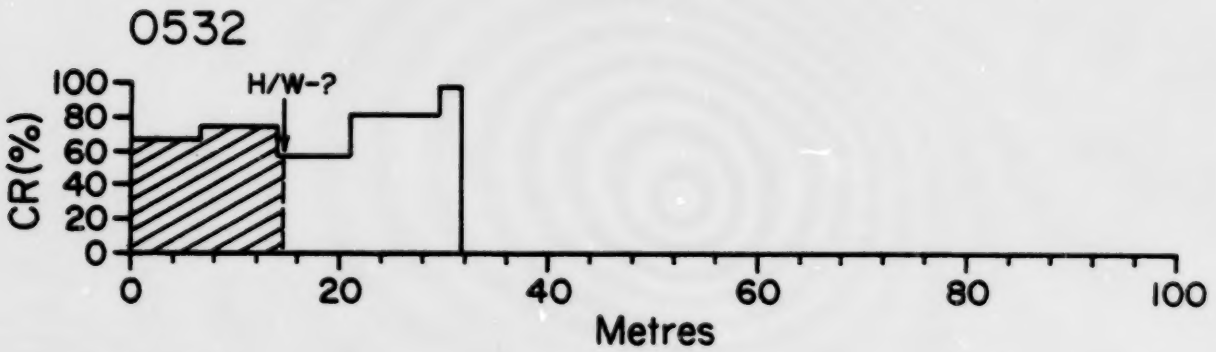
Core recovery logs, selected and re-appraised
from original diamond drill logs. Les Mines Selbaie

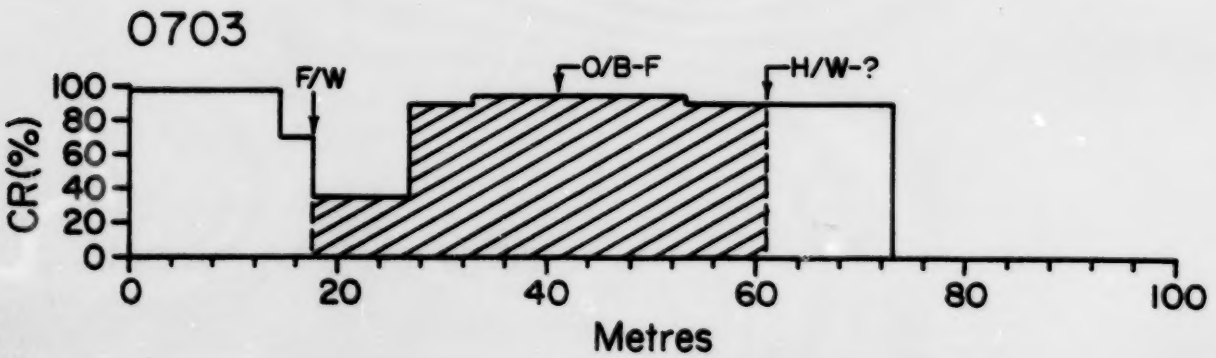
Legend

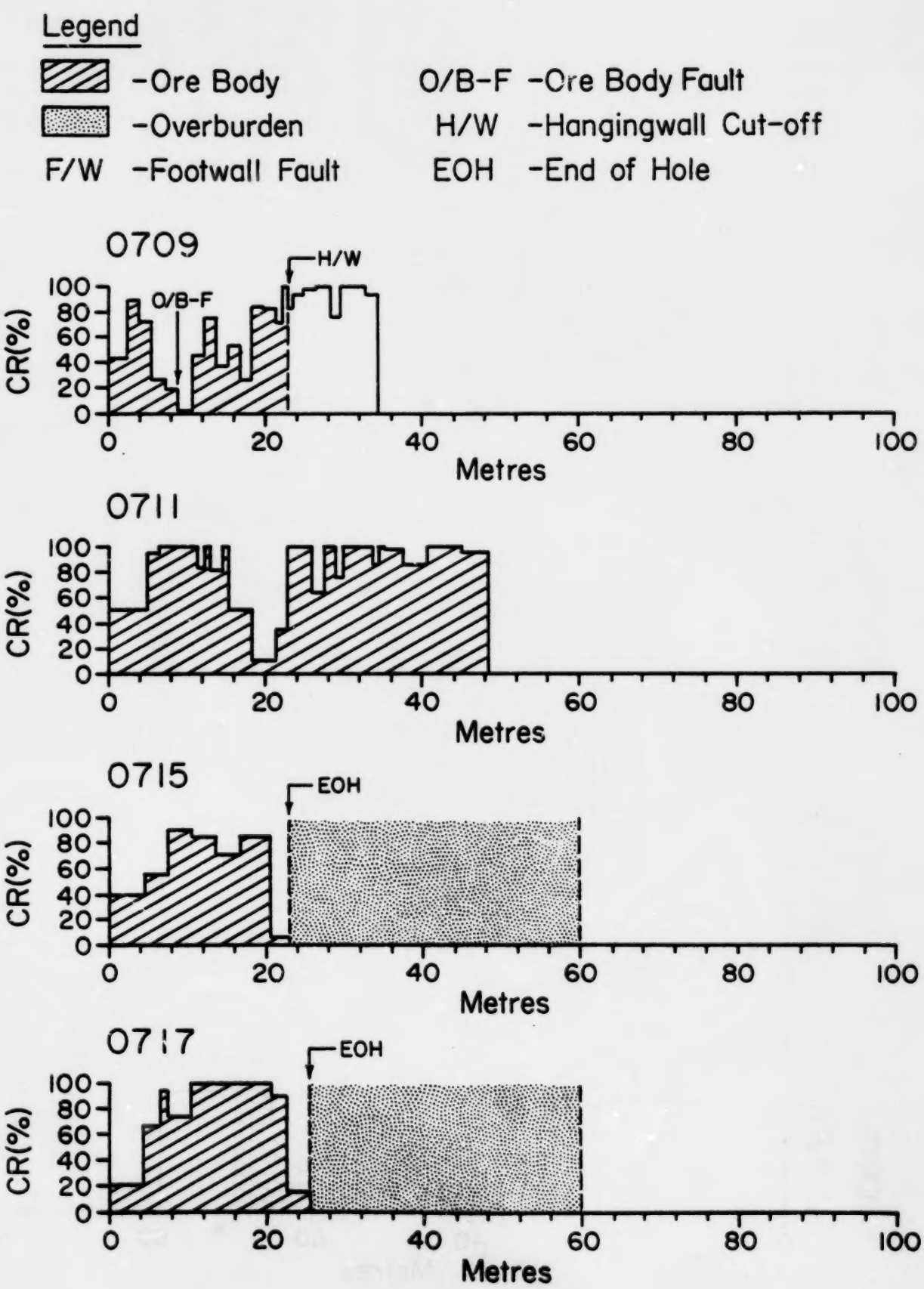
-Ore Body
-Overburden
F/W -Footwall Fault
O/B-F -Ore Body Fault
H/W -Hangingwall Cut-off
EOH -End of Hole





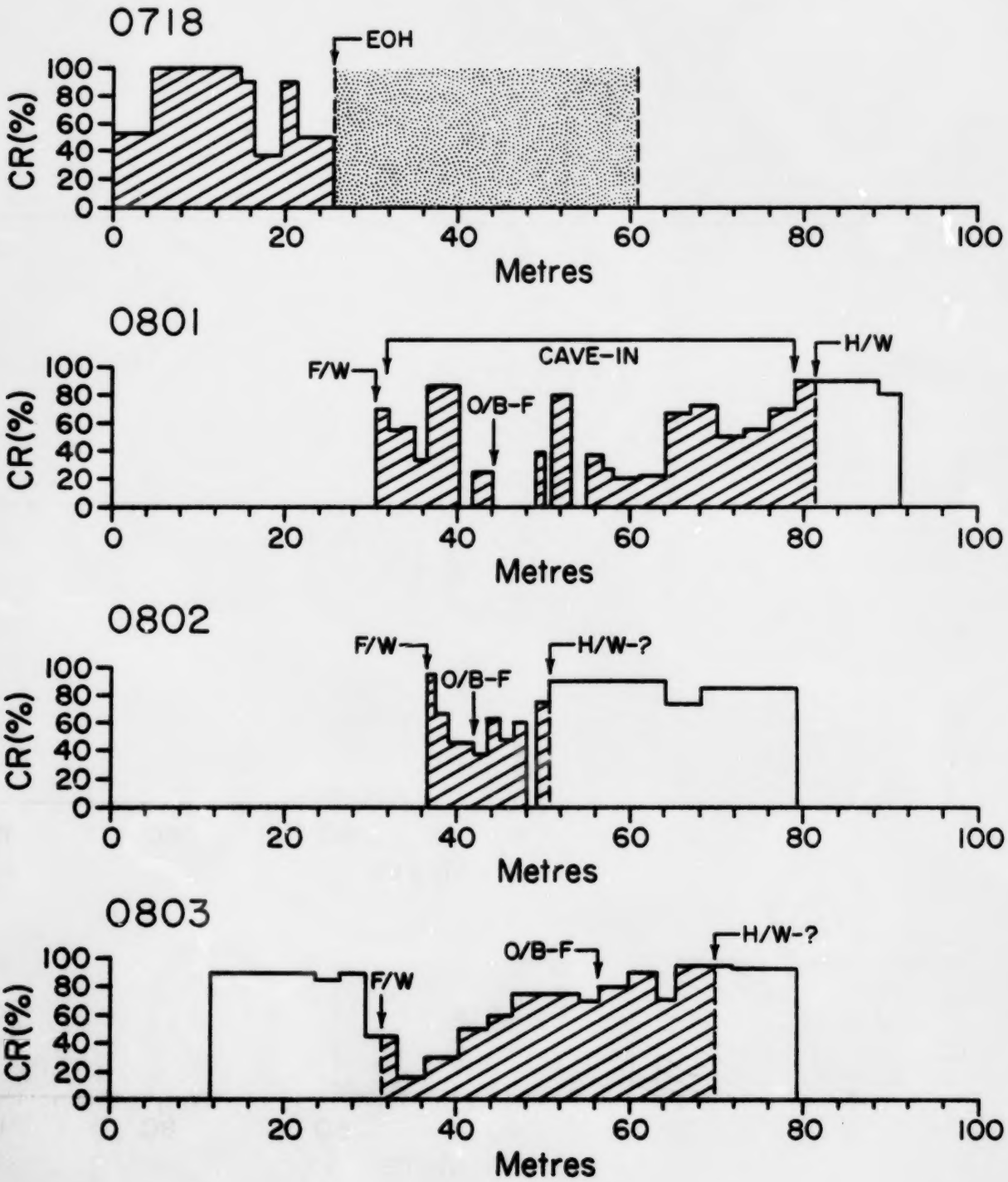


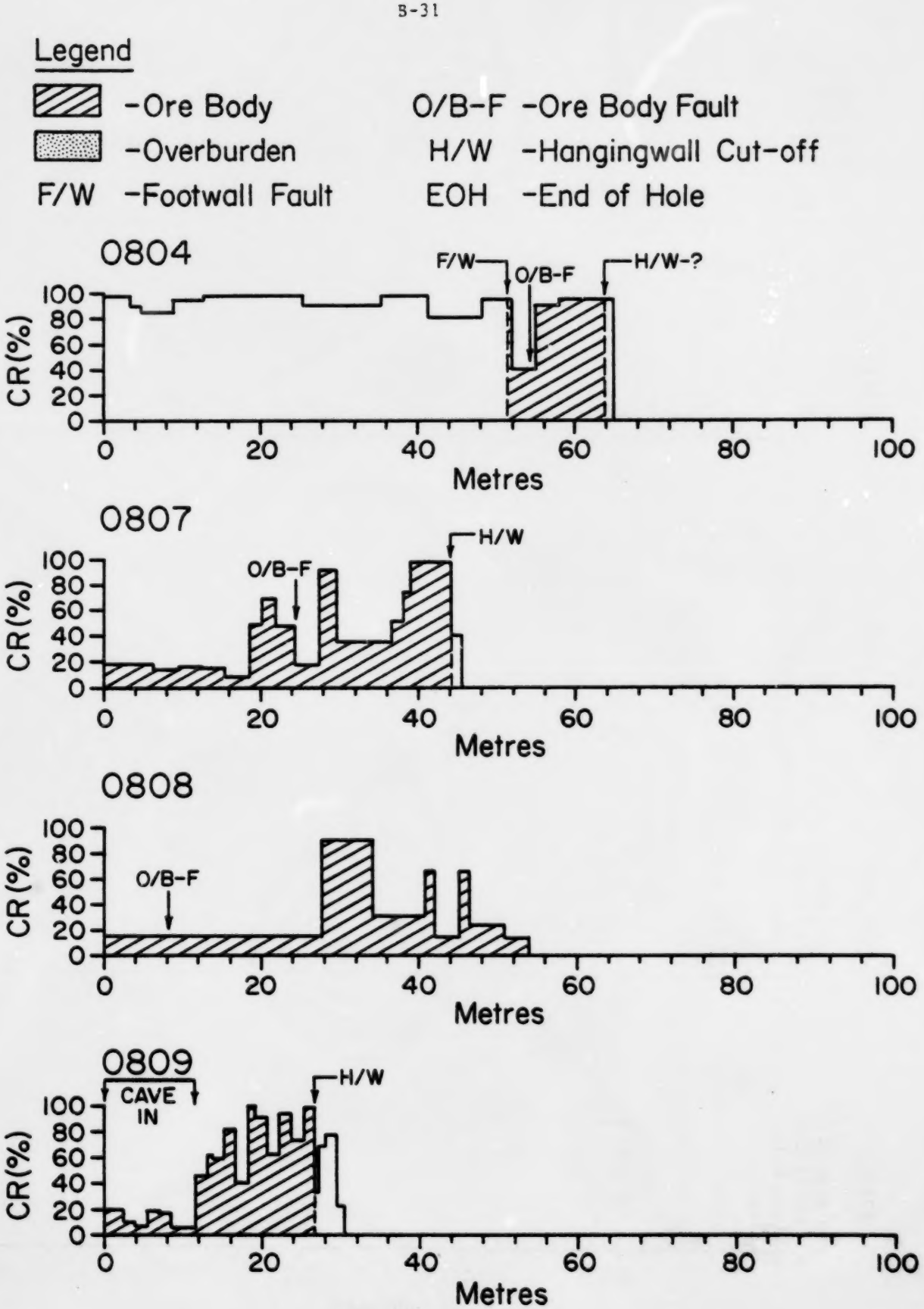



Legend
-Ore Body
-Overburden
F/W -Footwall Fault
O/B-F -Ore Body Fault
H/W -Hangingwall Cut-off
EOH -End of Hole
0709
H/W
O/B-F
CR(%)
100
80
60
40
20
0
0
20
40
60
80
100
Metres
0711
CR(%)
Metres
0715
EOH
CR(%)
Metres
0717
EOH
CR(%)
Metres

Legend

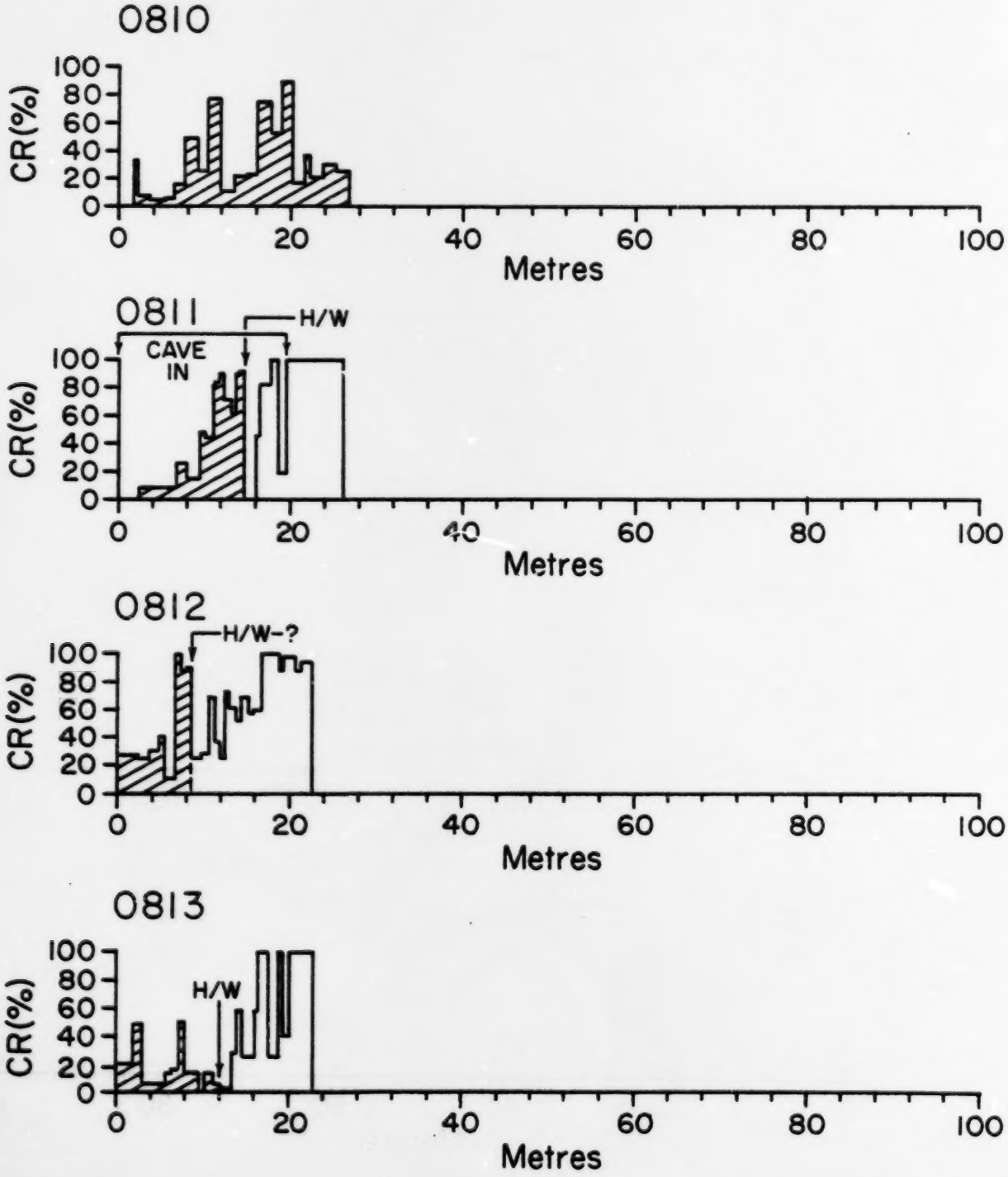
-Ore Body
-Overburden
F/W -Footwall Fault
O/B-F -Ore Body Fault
H/W -Hangingwall Cut-off
EOH -End of Hole

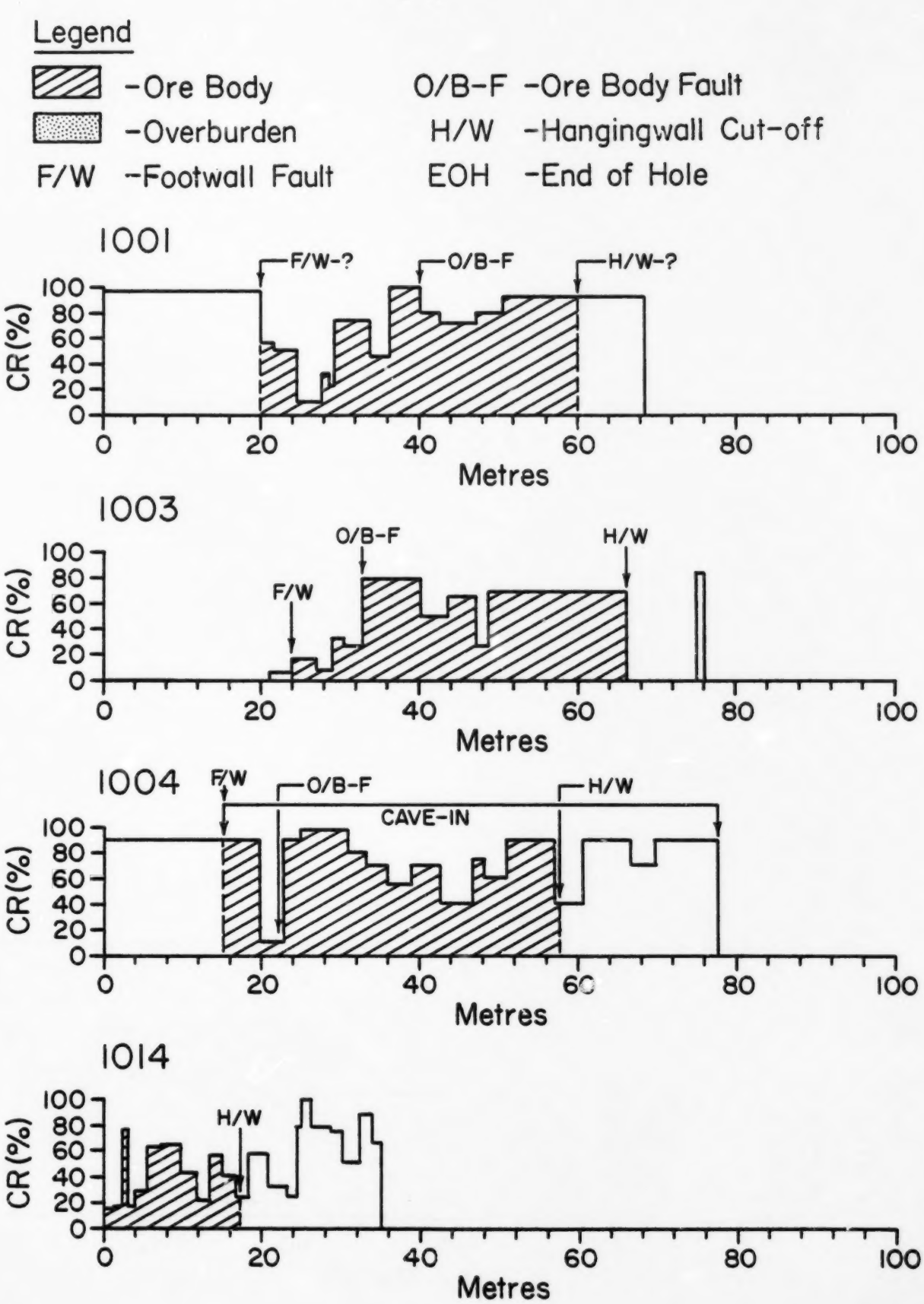


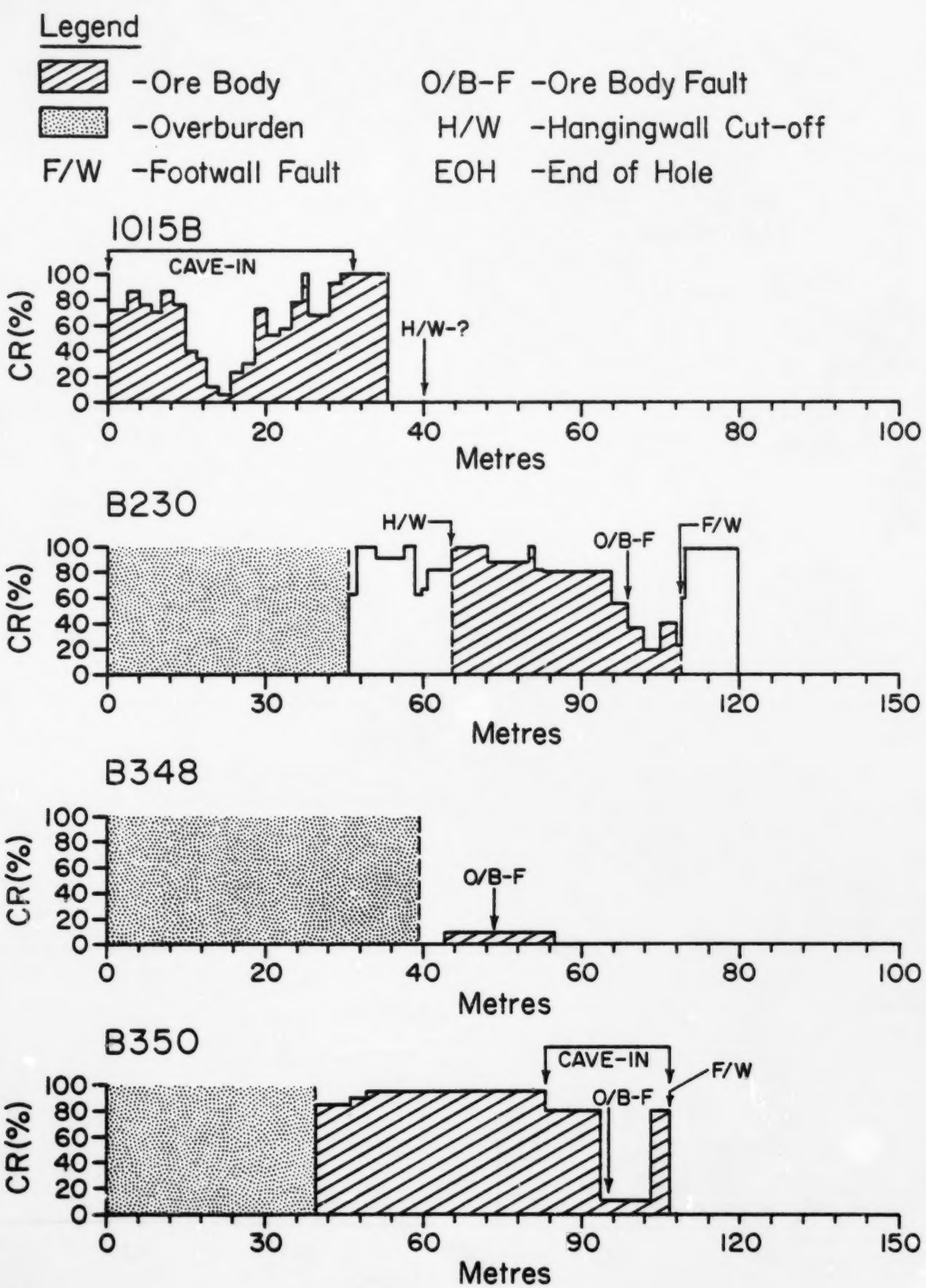

Legend
-Ore Body
-Overburden
F/W -Footwall Fault
O/B-F -Ore Body Fault
H/W -Hangingwall Cut-off
EOH -End of Hole
0804
F/W
O/B-F
H/W-?
CR(%)
100
80
60
40
20
0
0
20
40
60
80
100
Metres
0807
H/W
O/B-F
CR(%)
Metres
0808
O/B-F
CR(%)
Metres
0809
CAVE IN
H/W
CR(%)
Metres

Legend

-Ore Body
-Overburden
F/W -Footwall Fault
O/B-F -Ore Body Fault
H/W -Hangingwall Cut-off
EOH -End of Hole




Legend
-Ore Body
-Overburden
F/W -Footwall Fault
O/B-F -Ore Body Fault
H/W -Hangingwall Cut-off
EOH -End of Hole
1001
F/W-?
O/B-F
H/W-?
CR(%)
100
80
60
40
20
0
0
20
40
60
80
100
Metres
1003
O/B-F
H/W
F/W
CR(%)
Metres
1004
F/W
O/B-F
H/W
CAVE-IN
CR(%)
Metres
1014
H/W
CR(%)
Metres


Legend
-Ore Body
-Overburden
F/W -Footwall Fault
O/B-F -Ore Body Fault
H/W -Hangingwall Cut-off
EOH -End of Hole
1015B
CAVE-IN
H/W-?
CR(%)
Metres
B230
H/W
O/B-F
F/W
B348
O/B-F
B350
CAVE-IN
F/W
O/B-F

Legend

-Ore Body
-Overburden
F/W -Footwall Fault
O/B-F -Ore Body Fault
H/W -Hangingwall Cut-off
EOH -End of Hole